The Impact of Horizontal Velocity on the APFO Ground Control Database

By Louise Mathews and Joan Biediger
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Abstract

The Aerial Photography Field Office collects Ground Control Points for use in inspecting the horizontal accuracy of new imagery acquisitions. Great care is taken to ensure that the points used are accurate, in order to determine the quality of the new imagery. Slow positional shifts experienced in parts of the country subject to tectonic activity could lead to changes in the locations of these points. These potential positional shifts are currently not reflected in the corresponding control point coordinates in the database. In order to determine the level of potential change to coordinate positions caused by this two dimensional motion, know as horizontal velocity, all control points in the database were processed using the Horizontal Time Dependent Positioning (HTDP) software developed by the National Geodetic Survey (NGS) of the National Oceanic and Atmospheric Administration (NOAA). The test showed that the areas of seismic activity along the West Coast and Alaska could probably see a change in control point positions of over 2 meters after 50 years. However, most of the continental United States would see an extremely small change – generally 0.1 meter or less.

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Introduction and Background

The control point database created and maintained at the Aerial Photography Field Office (APFO) is a valuable resource. As the database continues to grow, and the ground control points contained in it are used to determine the horizontal accuracy of all current and future aerial imagery programs contracted by APFO, many considerations are involved in making sure the database is sound both theoretically and structurally. The control point database is maintained and updated on a regular basis. New points are added, and obsolete or inferior points are deleted from the database to maintain its integrity. To further enhance the value and overall integrity of the database, it was proposed that a study be conducted to determine if the earth's horizontal ground movement has a significant effect on the control points in the database.

According to the theory of plate tectonics the Earth's surface is in constant motion. As such, the ground control points in the database are not necessarily static entities. The control points in the database may be affected by a phenomenon called horizontal velocity.

Horizontal velocity, according to Snay (2003), is related to the horizontal movement on the earth's surface caused by tectonic plate movement and periodic displacements associated with earthquakes. The crustal motion of the earth can cause fixed reference points on the earth, such as ground control points, to move at predictable rates from year to year. In areas associated with higher rates of movement, such as the west coast – particularly California - this constant and predictable movement could potentially have an impact on ground control points collected in these areas, depending on the age and location of the points.

To address the possibility of point movement due to horizontal velocity, a study was proposed to assess the possible risk and possible implications to the control point database that this phenomenon may pose.

Plate Tectonics and Movement

The concept of plate tectonics was developed during the 20^{th} century. Initially it was somewhat controversial, but it has become a standard concept in the understanding of our planet's geology and geography. A simple explanation is that the earth's crust is made up of rigid blocks which are in continuous motion. When the plates move against each other, they cause different types of deformations, resulting in earthquakes and volcanoes. Mountains are created when one plate is subducted, or moves under, another, pushing the landmass upwards.

In the continental United States, almost all of the country lies on the relatively stable North American Plate; a small area, in western California, lies on the Pacific Plate. The North American Plate includes all of Canada and Alaska; according to a USGS map, it also includes the northeastern part of the Russian Federation, and the northeastern part of Japan. It is the "outer" plate for much of the Ring of Fire, the semi-circular pattern of volcanoes formed by the movement of the Pacific plate underneath adjacent plates.

Figure 1 displays the major plate boundaries in the world, with red arrows denoting the directions of motion. The Pacific plate is moving sideways against the North American plate, in what is called a transform fault; this appears to be one of the largest major transform faults over a land area in the world. This fault zone is the area of primary concern in studies of horizontal velocity, and the one which has the most affect on the potential change in position of points in the APFO Ground Control Database.

The boundary of the Pacific and North American plates in California is the familiar San Andreas Fault, shown in Figures 2 and 3. The destruction caused by earthquakes along this fault line is well known.

In other parts of the map, arrows are moving in opposite directions. These are areas of seafloor spreading, and the Rift Valley in Africa. In other areas, the arrows are pointed towards each other. In many cases, these are subduction zones, where one plate is sliding under the other. These areas frequently see volcanic activity, as is the case in the Pacific Northwest, and the Aleutian Island chain in Alaska. These areas are also a concern for a horizontal velocity study, since APFO does contract imagery in Alaska, Hawaii, and the Pacific Basin.

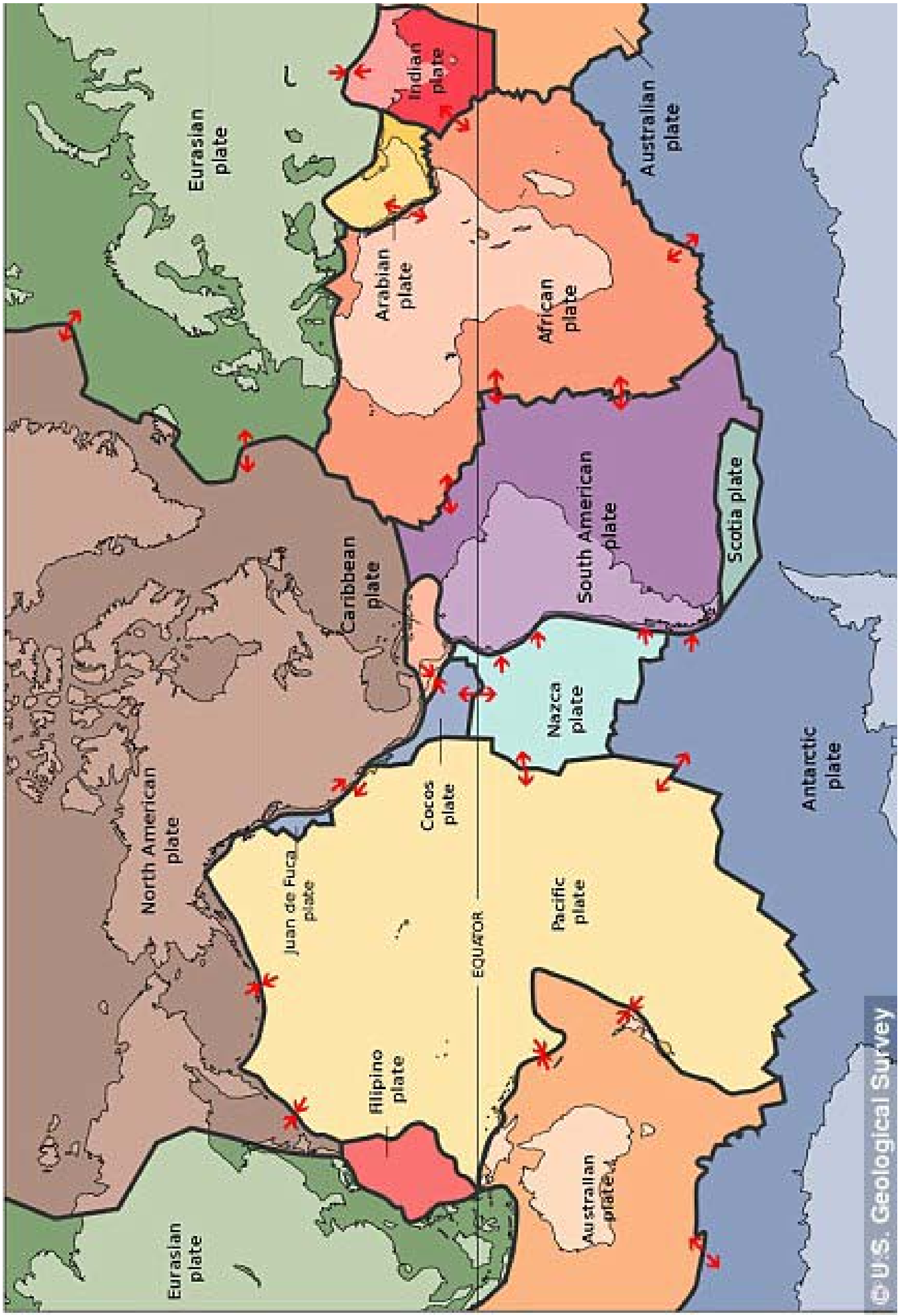

Figure 1: Major tectonic plates, showing direction of movement. Graphic by USGS, from geology.com

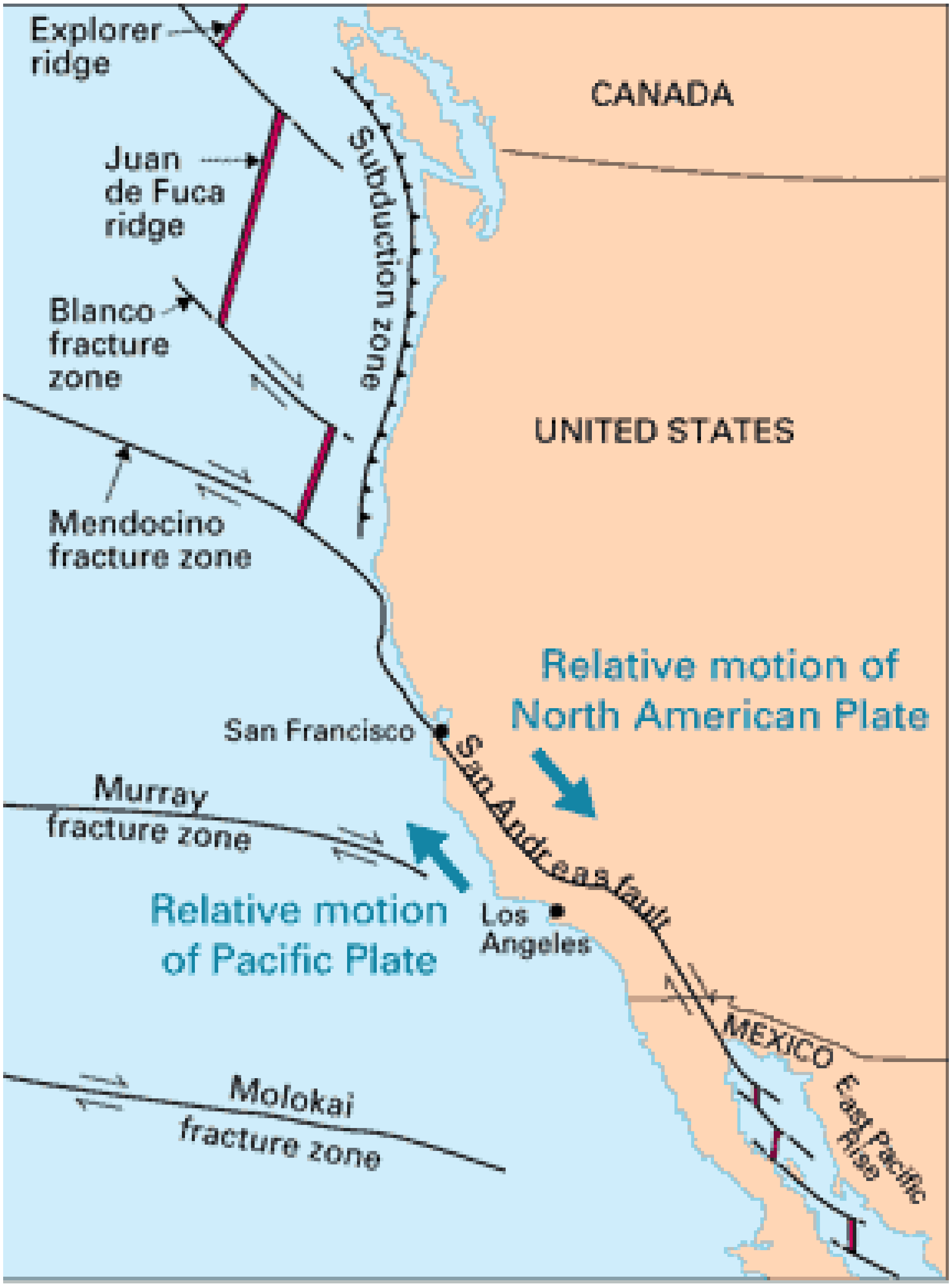

Figure 2: Plate activity on the U.S. west coast. Graphic from Kious, et al, from usgs.gov

California, particularly the area of the San Andreas Fault, receives a great deal of attention from state and federal agencies dealing with geodetic control, and the potential for movement is being carefully monitored and measured. The National Geodetic Survey (NGS) and other groups are constantly updating their models for ground movement.

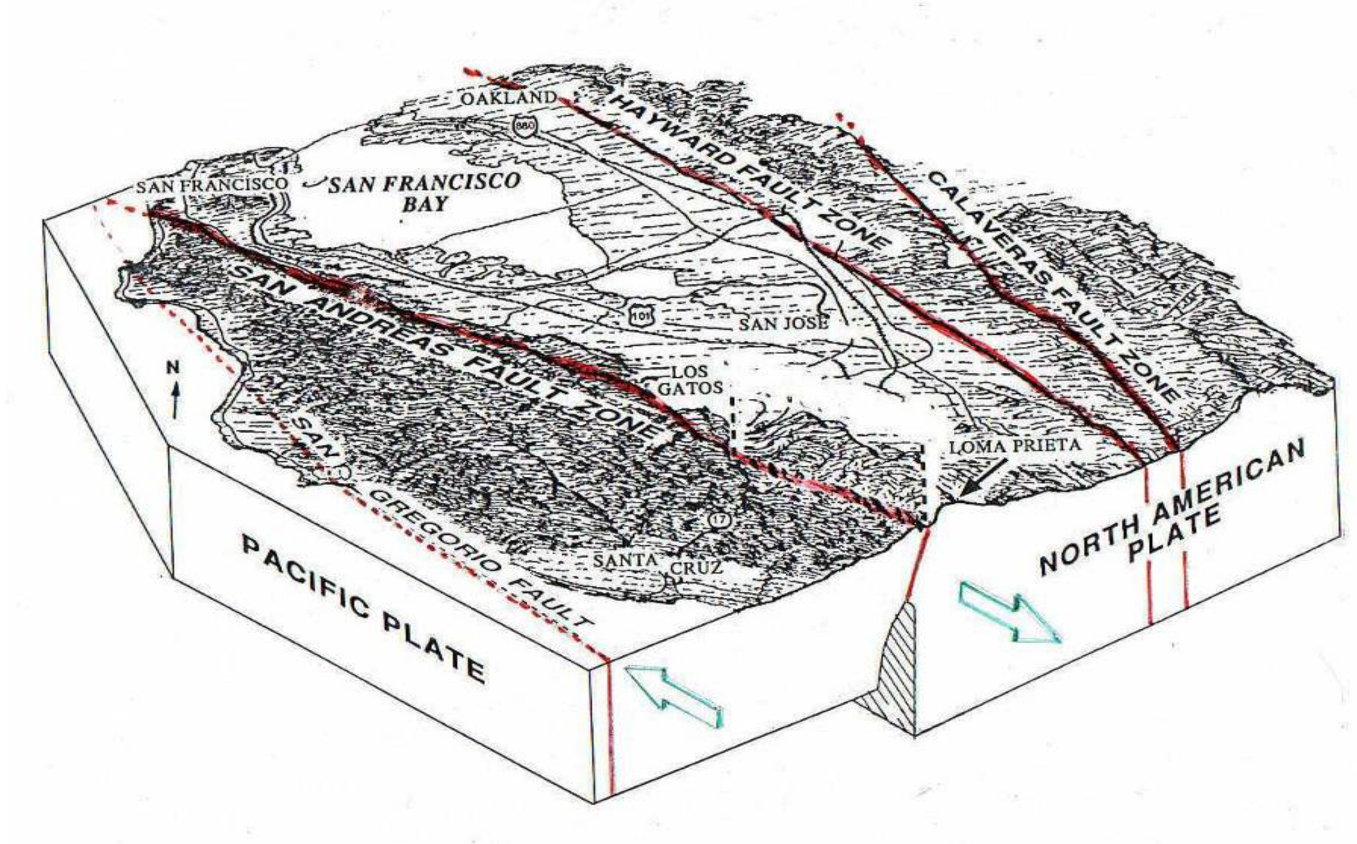

Figure 3: Plate activity south of San Francisco. Graphic from Snay, 2007.

The San Andreas fault moves offshore in the area of San Francisco. Further north, the boundary with the Pacific Plate moves to the west. Three smaller plates, Juan de Fuca, Gorda, and Explorer, encounter the North American Plate in a subduction zone. The Juan de Fuca plate is moving under the North American plate, and as a result volcanism, such as the eruption of Mt. Saint Helens, is more common in the Pacific Northwest.

This motion is clearly illustrated in Figure 4, showing the movement of the Juan de Fuca plate under the North American plate. As the plate moves downwards, it is heated, and becomes a part of the mantle. It then becomes part of the magma which rises to the surface through volcanoes.

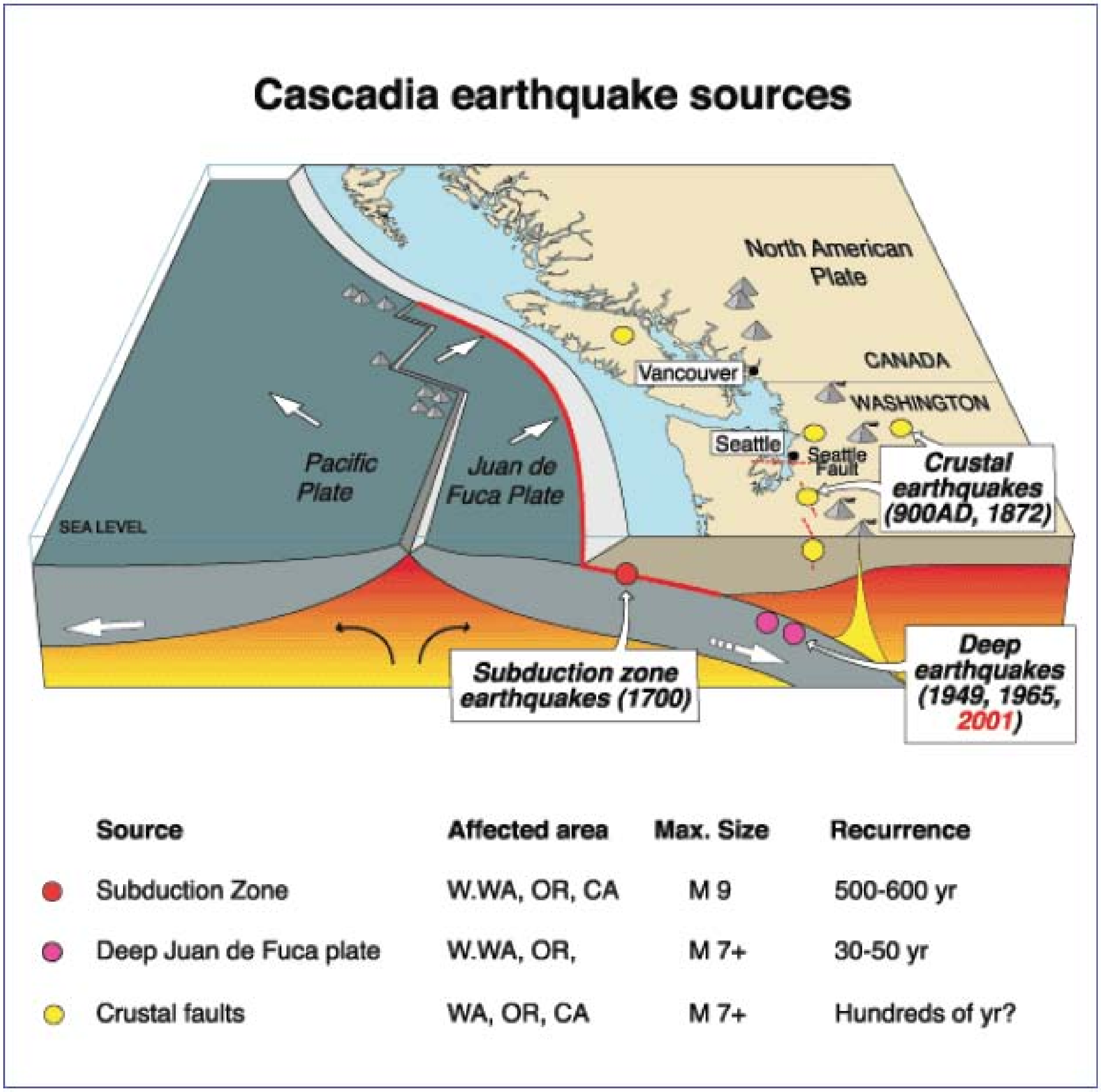

Figure 4: Subduction zone west of Washington/British Columbia, as the Juan de Fuca plate moves under the North American plate.. Graphic by Snay and Pearson, 2010. GET PERMISSION

The Ring of Fire, created through this process of subduction and volcanism, continues in an arc shaped pattern across the northern Pacific, along the Aleutian Islands, where the Pacific plate is subducted into the Aleutian Trench. Alaska has a great many active or potentially active volcanoes, and, like California, is closely monitored. The chain of volcanoes continues in the Kamchatka Peninsula of Russia. as the Pacific Plate moves under the North American Plate.

Alaska is another area of seismic activity which rivals the California coast in the potential for movement. APFO does have some control points in Alaska, which have been used in inspecting Resource Program imagery, and thus need to be considered.

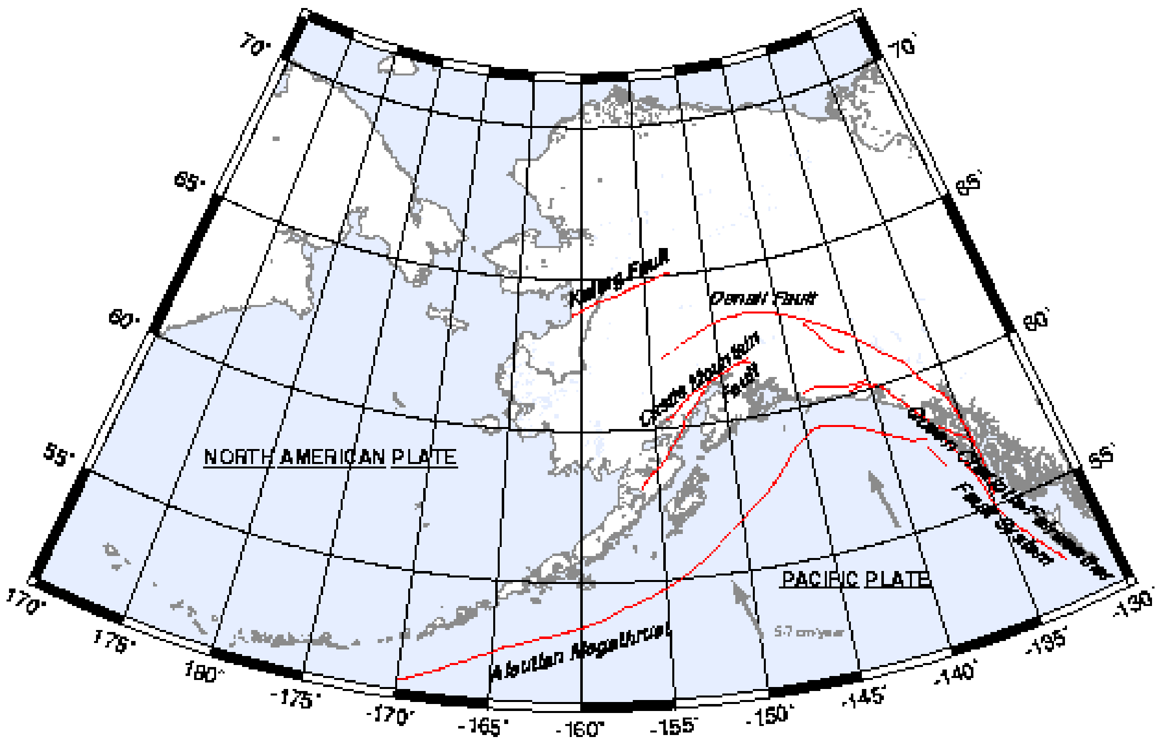

Figure 5: Subduction zone along the southern coast of Alaska, as the Pacific plate moves under the North American plate. Graphic from Alaska Earthquake Information Center.

Plate tectonics is a fascinating topic with a large body of literature available for further reading. There are also many articles on horizontal velocity, the movement of individual points on the land area, due to tectonic activity. Many of these are written by Richard Snay and/or Chris Pearson of the National Geodetic Survey (NGS), who have worked with the Horizontal Time Dependent Positioning (HTDP) model. This more specific focus within the plate tectonics field has relevance to the accuracy of digital aerial photography acquired by APFO. A clear statement of the problem was given by Snay and Pearson (2007):

> As a result of its proximity to this plate boundary [North American and Pacific], a zone a few hundred km wide-- including most of California, Nevada, Oregon, Washington and Alaska-- is deforming. This deformation causes the relative position of points on the Earth to change with time. Consequently, survey measurements taken at different times will differ, and we must have some method to compensate for this change, or the resulting coordinates will contain biases.

The authors explain that there are two different processes of deformation to consider within this zone. The first is the "secular field," which "represents the response of the crust in the plate boundary zone to the differential movement of the two tectonic plates." The rate of movement could exceed 5 cm per year, which would be over 2.5 meters after 50 years. The rate of this movement is felt to be fairly constant, although the models of deformation will be updated as knowledge of the processes grows.

The second process is the unpredictable and sudden change which results from an earthquake. The consequent positional change is calculated using a dislocation model, while the secular changes are predicted through interpolation.

Horizontal Time Dependent Positioning (HTDP) Software

The practical application of the HTDP models is found by using the software, which

> … incorporates numerical models for plate motion, allowing users to apply HTDP to estimate horizontal velocities anywhere in CONUS [the continental United States] as well as in parts of Alaska. HTDP also incorporates recent numerical models for most of the recent U.S. earthquakes greater than 6.0 on the Richter scale. These models enable HTDP users to estimate the crustal displacements associated with the earthquakes. Taken together, the crustal velocity models and the earthquake models enable HTDP users to update (or backdate) horizontal coordinates measured on one date to corresponding coordinates that would have been measured on another date. (Snay and Pearson, 2010)

This can allow the user to create a data set which is "time-homogenized," in which all the coordinates would have the same temporal frame of reference.

The California Spatial Reference Center gives the accuracy of HTDP in 2002 was given as ± 0.5 cm (D'Onofrio, et al, 2002).

The software has had several versions, as it is updated periodically. The most current version is 3.2.1, released in June, 2011. From the software's guidebook:

> HTDP uses a model developed by Dr. Robert McCaffrey and updated by Dr. Christopher Pearson to estimate horizontal velocities for points located in the western United States whose latitudes range from 31ºN to 49ºN and whose longitudes range from 100ºW to 125ºW. HTDP uses a model developed by Dr. Pearson to compute horizontal velocities for points located in Alaska whose latitudes range from 55ºN to 66ºN and whose longitudes range from 131ºW to 163ºW. Also, HTDP uses rigid plate models to estimate horizontal velocities for other areas of the world, including the eastern United States.

The models assume that movement on the plates is constant, except in areas of seismic activity, where equations based on dislocation theory are used. The guide lists the models which have been incorporated into HTDP. The model derived by McCaffrey and Pearson considers the western part of the United States as an area of elastic, rotating blocks separated by geologic faults, and included 6,287 horizontal velocities derived from repeated GPS observations. More detailed explanations can be found in the guide (Snay, 2011) and other publications; these are definitely worth reading.

HTDP software was written in FORTRAN, and opens with a Main Menu listing five options: predicting displacements, predicting velocities, updating positions, and transforming either positions or velocities between reference frames. As expected, a predicted displacement would be the velocity multiplied by a time period.

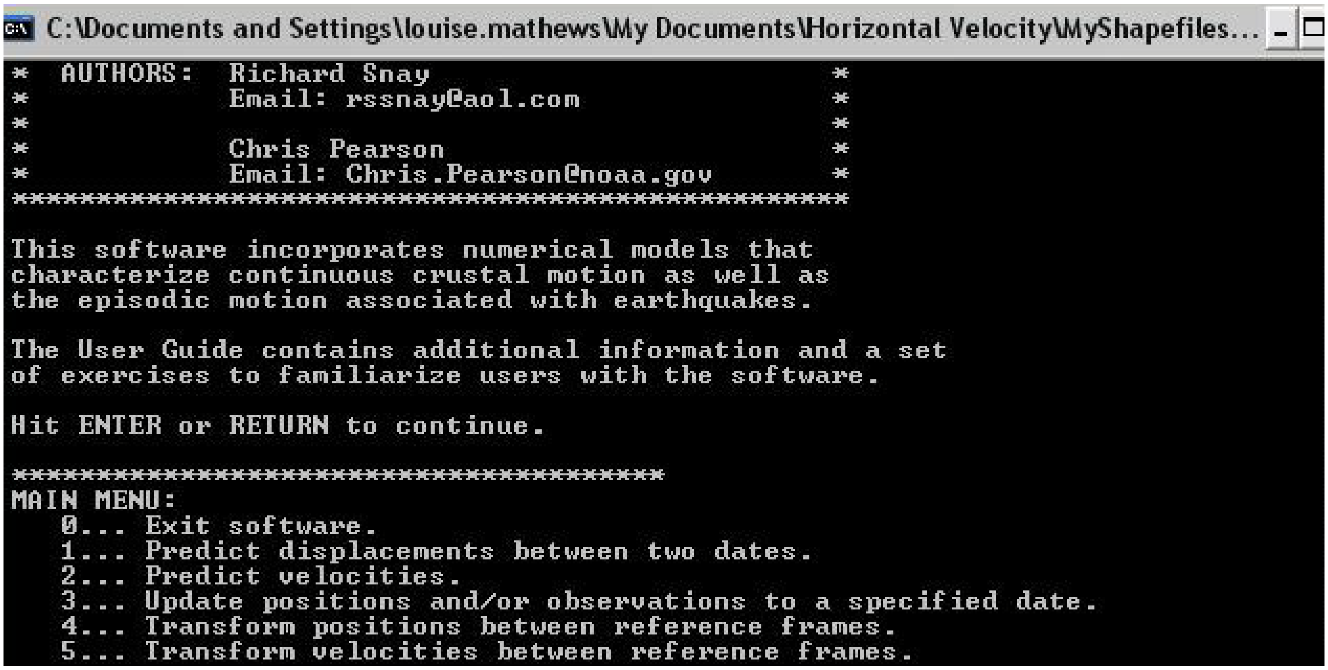

Figure 6: The Main Menu in the HTDP software

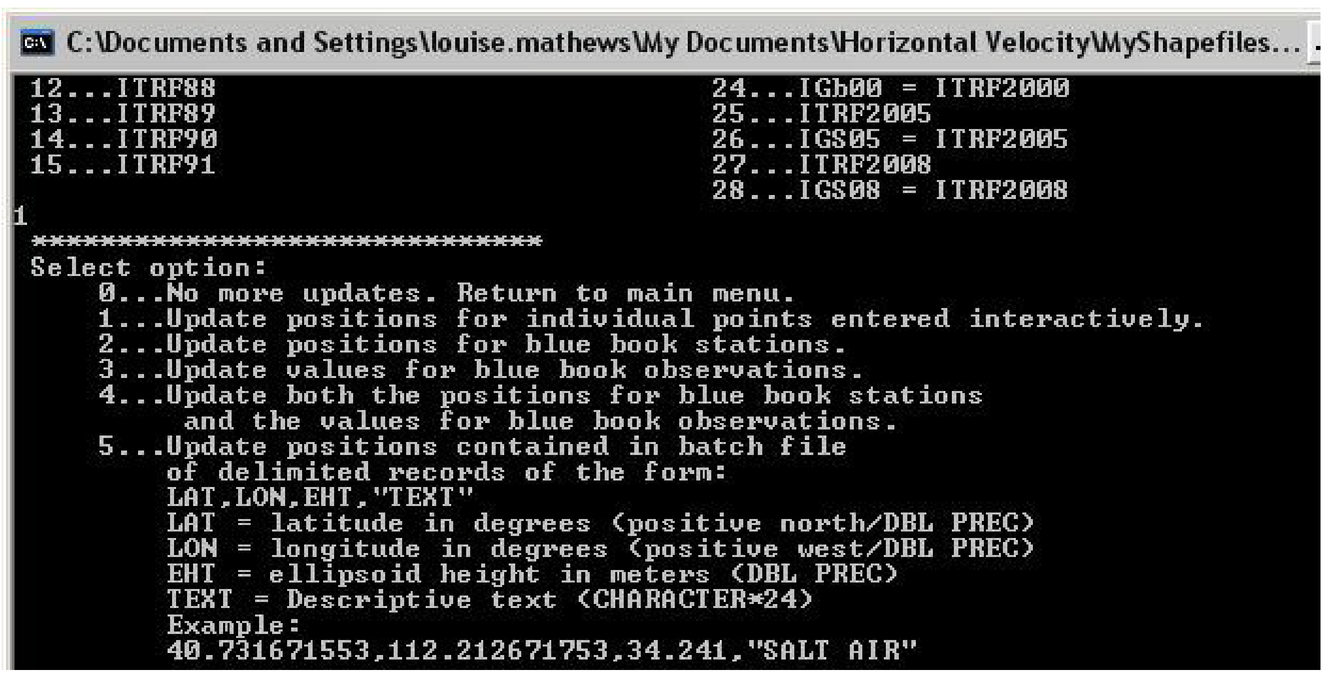

Figure 7: The options for entering data in the HTDP software

The software will work with individual points entered interactively (as degrees, minutes, and seconds), with batched points in the Blue Book format, and with points in a batch file using coordinates in decimal degrees and meters. A descriptive name must also be included, in quotes. This batch file option is new – it was introduced on July 19, 2011. It works well with the APFO Control Point database; the APFO ID name and decimal degree coordinates can be easily extracted from point shapefiles for the states, and formatted for use in the HTDP software. The results can again be formatted to calculate the predicted distance of movement (from north and east velocities) and this table can be joined to the original point shapefile and used for display with appropriate symbology.

The software also will transform coordinates between reference frames. The guide explains:

> Internal to the software, velocities are expressed relative to the International Terrestrial Reference Frame of 2008 (ITRF2008) as defined by Altamimi et al. [2011]. Velocities relative to other reference frames are obtained from their corresponding ITRF2008 velocities using transformation equations adopted by NOAA's National Geodetic Survey.

The present software version includes 28 options to choose from; although many in actuality use one of the other options (Options 29 and 30 use option 1, the NAD_83, as does WGS_84). Note that the three NAD_83 options each work with a different fixed plate (North American, Pacific and Marianas).

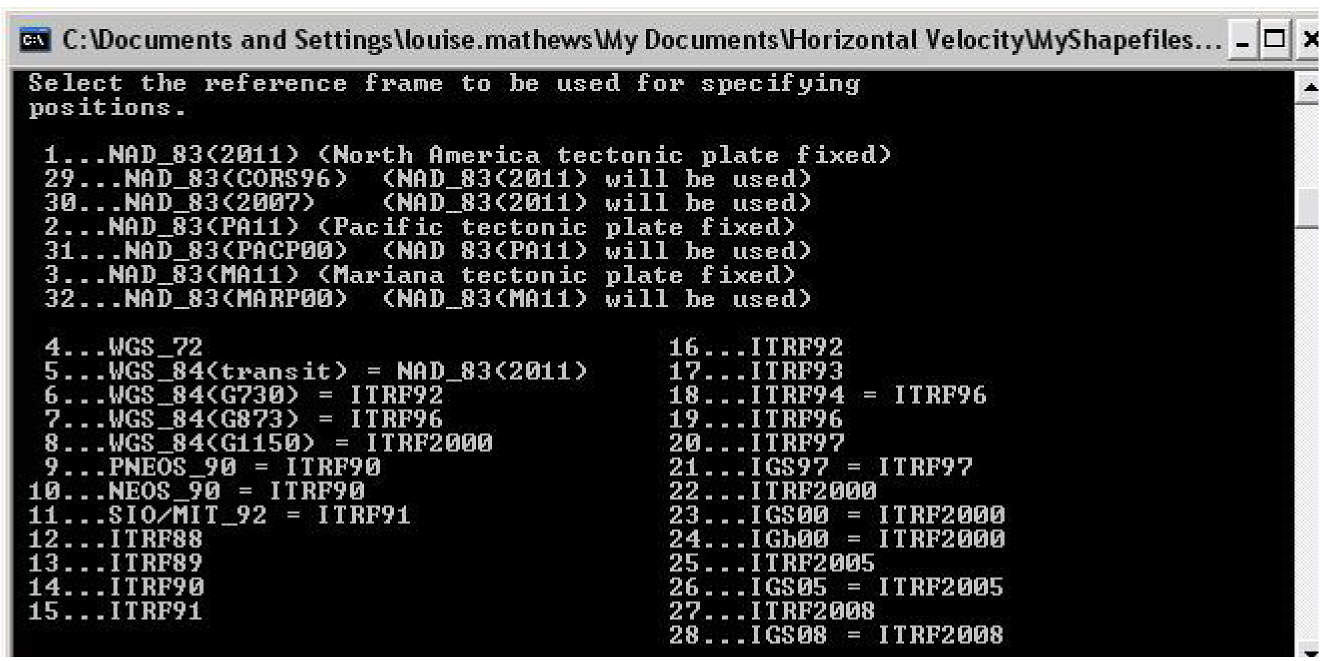

Figure 8: Available Reference Frames in the HTDP software

The software can generate a line or grid of points from a given starting place, with a specified frame of reference and time position.

The example in Figure 9 shows the estimated velocities relative to NAD 83 (CORS96). The highest rates of movement are offshore, and would be about 0.5 meters in 10 year's time. Notice the change in direction of the arrows in the area just south of Eureka, California, as the transform fault is replaced by the subduction fault, and the symbology color changes from red to yellow.

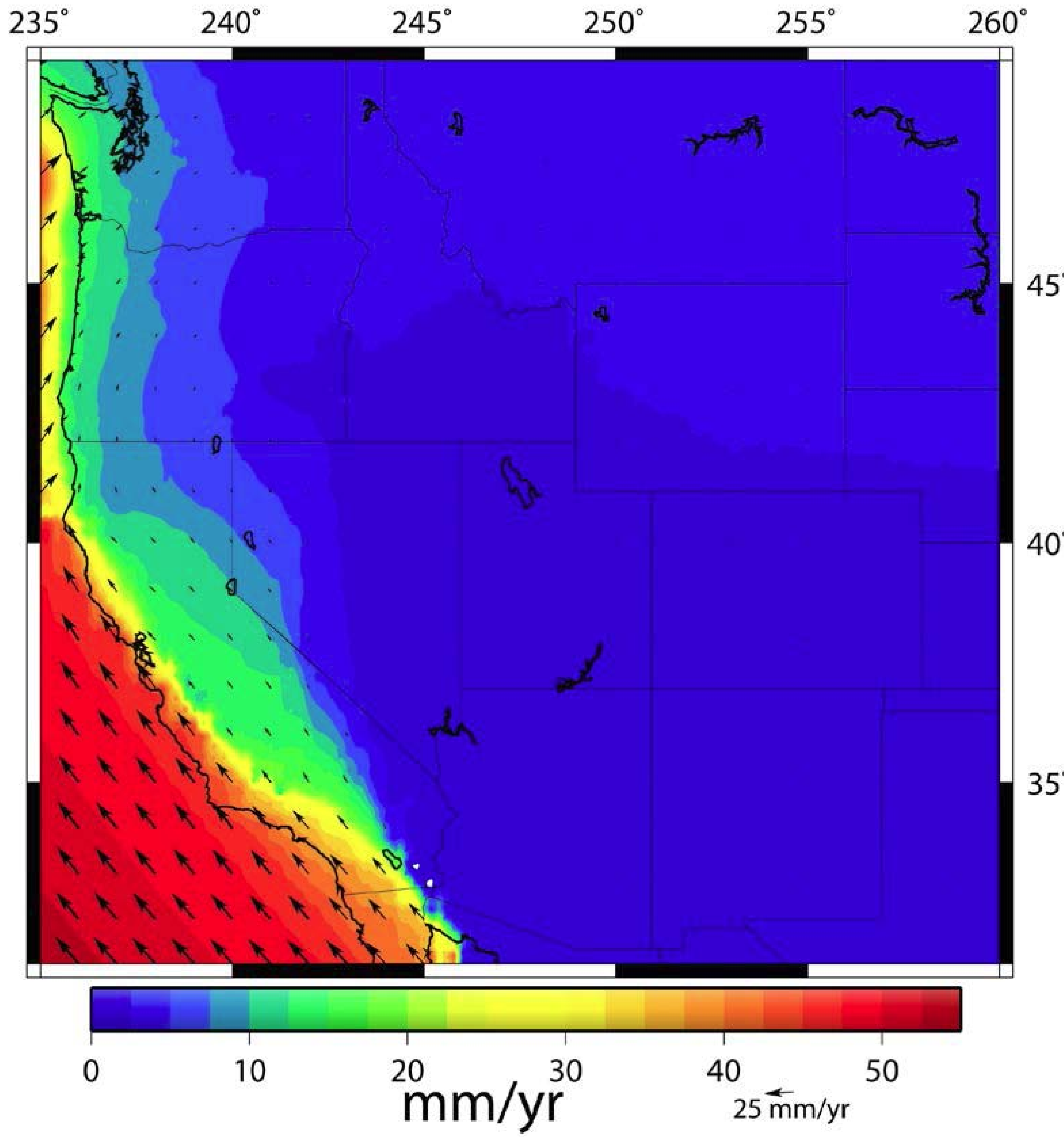

Figure 9: Horizontal velocities along the California coast, where the North American and Pacific plates slide past each other in a transform fault. Graphic from the User's Guide to the HTDP software, Snay and Pearson, 2011.

In Figure 10, a similar map of the Alaska coastline shows the Pacific plate moving under the North American plate in a subduction zone. As with California, the higher velocities are offshore.

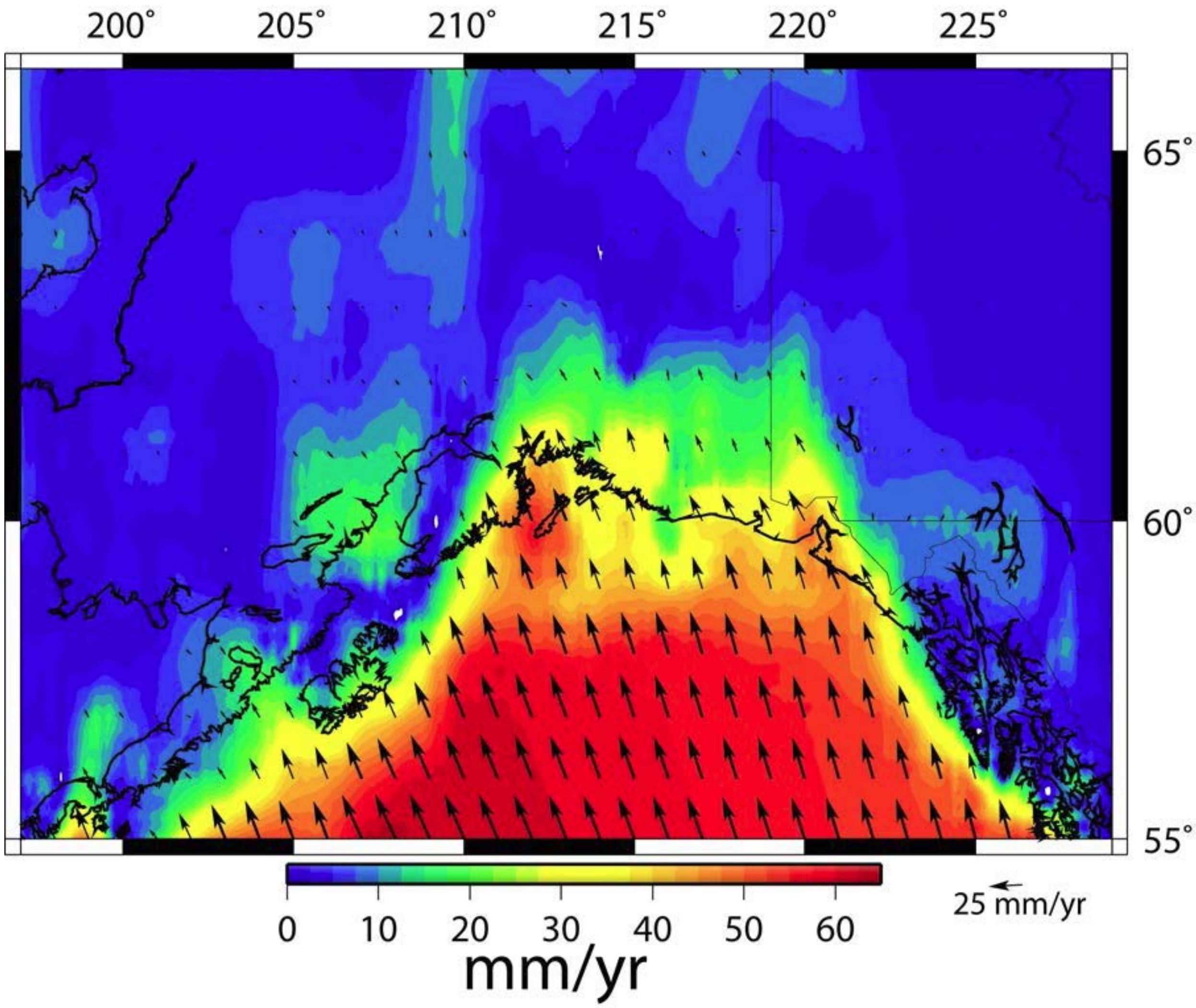

Figure 10: Horizontal velocities along the Alaska, where the Pacific plates moves under the Pacific plate in a subduction zone, called the Aleutian Trench.
Graphic from the User's Guide to the HTDP software, Snay and Pearson, 2011.

Methodology

This study was conducted by calculating estimated displacements 50 years into the future for all control points in the APFO control point database, using batch files for each state. The starting date was January 1, 2012 and the ending date January 1, 2062. The assumption was made that all points are currently in the correct position, although it is very likely that some of the points in the areas of seismic activity may already be as much as 50 years old, and may have already moved from the position in the database. In an ideal real world application, it might be advisable to re-calculate the position (if an epoch date were available) or to re-measure the point with a GPS unit.

The total distance of projected movement was calculated from the north and east displacements which were output from the HTDP program, and were recorded with no indication of the direction of movement. The steps of the process were:

1) Save the .dbf file from the shape file as an .xlsx file, and delete all columns except the latitude, longitude, and APFO ID. Organize the columns so that they are in the order Lat-Long-ID, and convert the longitude values to positive. Save as a .csv file. (For use in the change of reference frame module a ellipsoid height value is also needed).

LAT	LON	APFO_ID
60.123456000	180.987654000	ex003_987_13
59.987896000	180.984563000	ex003_988_13
59.985997000	180.988535000	ex004_989_13
59.989123000	180.982793000	ex005_990_13

Table 10: A mock .txt file saved from the .dbf file from the shapefile

2) Change the .csv extension to .txt, and add parentheses around the APFO ID names. (This was more easily batched in Word Pad than in Excel.) Delete the column titles and be certain that the first record is on the first line of the file.

```
60.123456000,180.987654000,"ex003_987_13"
59.987896000,180.984563000,"ex003_988_13"
59.985997000,180.988535000,"ex004_989_13"
59.989123000,180.982793000,"ex005_990_13"
```

Table 2: A mock .txt file edited for use in the HTDP software

3) Open the program *htdp.exe*, and select Option 1, “Predict displacement between two dates.” Follow the questions, adding the dates in a month, date, year format and

choosing NAD_83 (2011) as the reference frame. Choose to use a batch file, and enter the name of the .txt file prepared in the previous step. Exit the process when completed.

4) Check the output file to be sure that all of the values have been calculated correctly, and that the file is complete and correct. Correct any problems and re-run if necessary. (These would usually be errors in the name stemming from the process of putting the APFO_ID name into parentheses.)

HTDP (version 3.1) OUTPUT
DISPLACEMENTS IN METERS RELATIVE TO NAD_83(2011)
FROM 01-01-2012 TO 01-01-2062 (month-day-year)
FROM 2012.000 TO 2062.000 (decimal years)

NAME OF SITE	LATITUDE	LONGITUDE	NORTH	EAST
ex003_987_13	60 07 24.4416 N	180 59 15.5544 W	-0.024	0.078
ex003_988_13	59 59 16.4256 N	180 59 04.4268 W	-0.024	0.077
ex004_989_13	59 59 9.5893 N	180 55 18.7260 W	-0.024	0.079
ex005_990_13	59 59 20.8428 N	180 58 58.0548 W	-0.024	0.083

Table 3: A mock .txt file output from the HTDP software

5) Open Excel, and then open the output text file containing the results. Delete the header information. Calculate the distance using the Pythagorean theorem. Delete all columns except NAME OF SITE and distance. Save as an .xls file.

6) Open ArcMap and add the corresponding state shapefile. Join the table to the shapefile, using the APFO ID (NAME OF SITE) as the common field. Check to be sure that all records have a distance calculated. Export the file as a feature class into the geodatabase of state files.

7) Add the previously created symbology layer file for the state's points so that they will match the rest of the display.

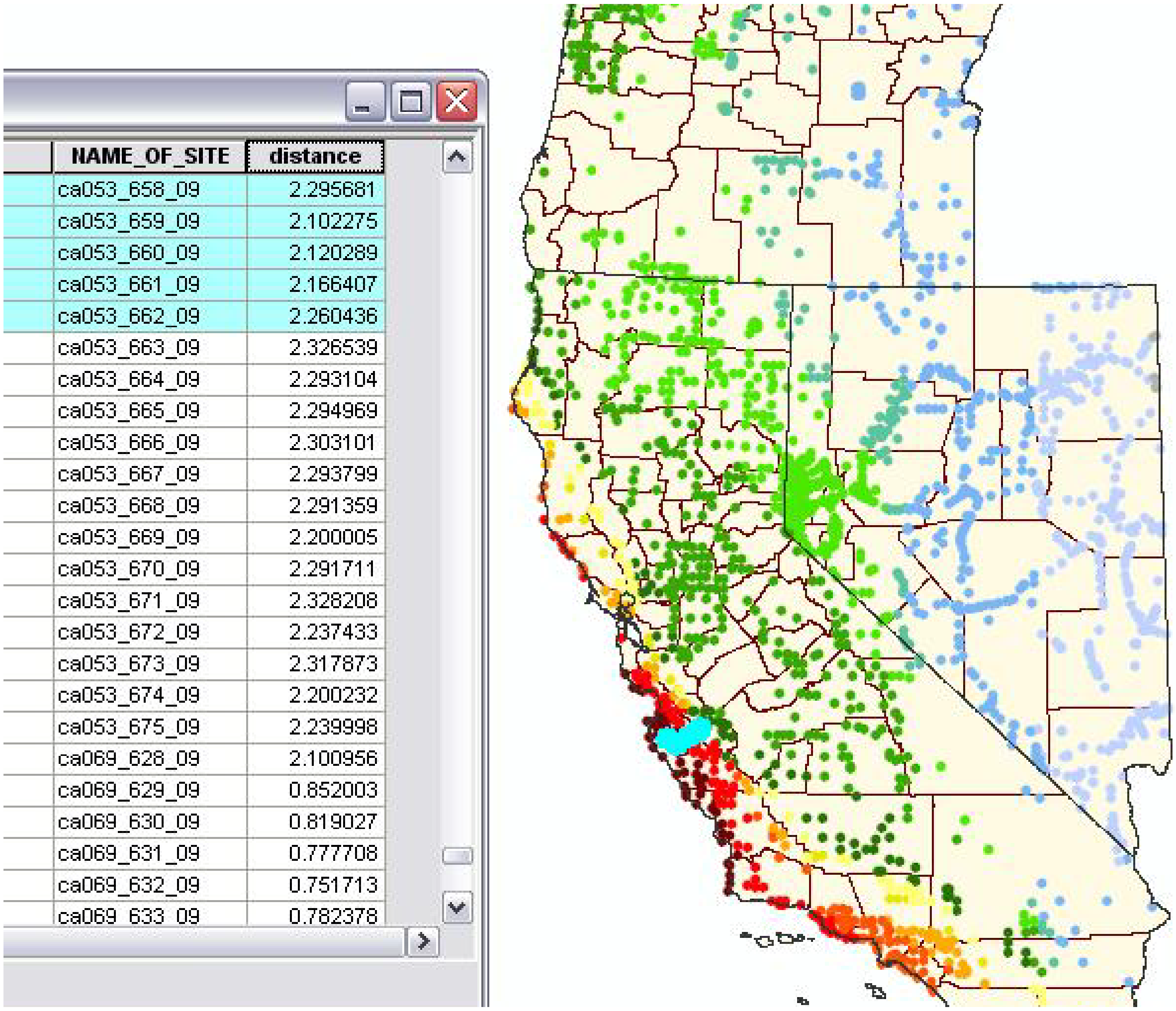

Figure 11: The distance moved has been calculated from the output file in Table 3, and joined to the point shapefile for the state.

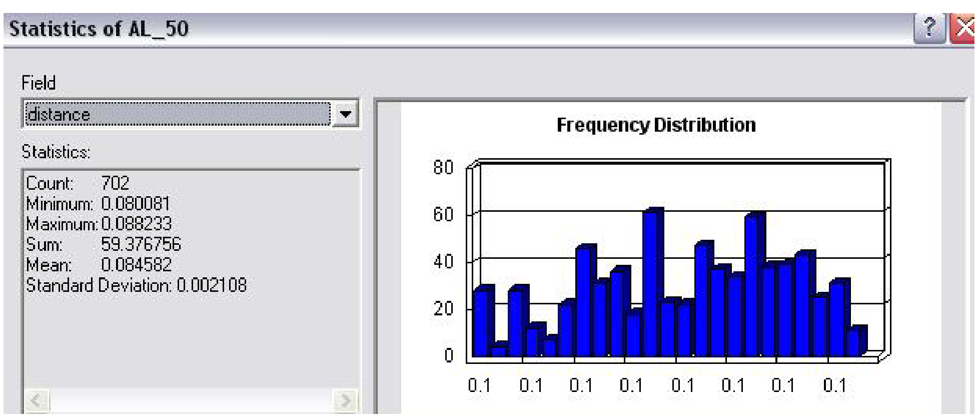

Figure 12: The range of estimated values in Alabama is 0.008 meters from highest to lowest, with a mean of 0.084582meters. Many states have a low mean and small range.

Results

After the process of finding displacement values was completed for all states, the same symbology was applied to each file. As expected, the pattern was similar to that of the maps in NGS articles and presentations. The projected displacement is greater than 1 meter only in western California, in a band trending from southeast (including about ¾ of the Mexican border) to northwest, to the area where the transform fault moves offshore and the subduction zone takes over. Larger displacements continue along the Oregon and Washington coasts to British Columbia, but they are not as great as those in California.

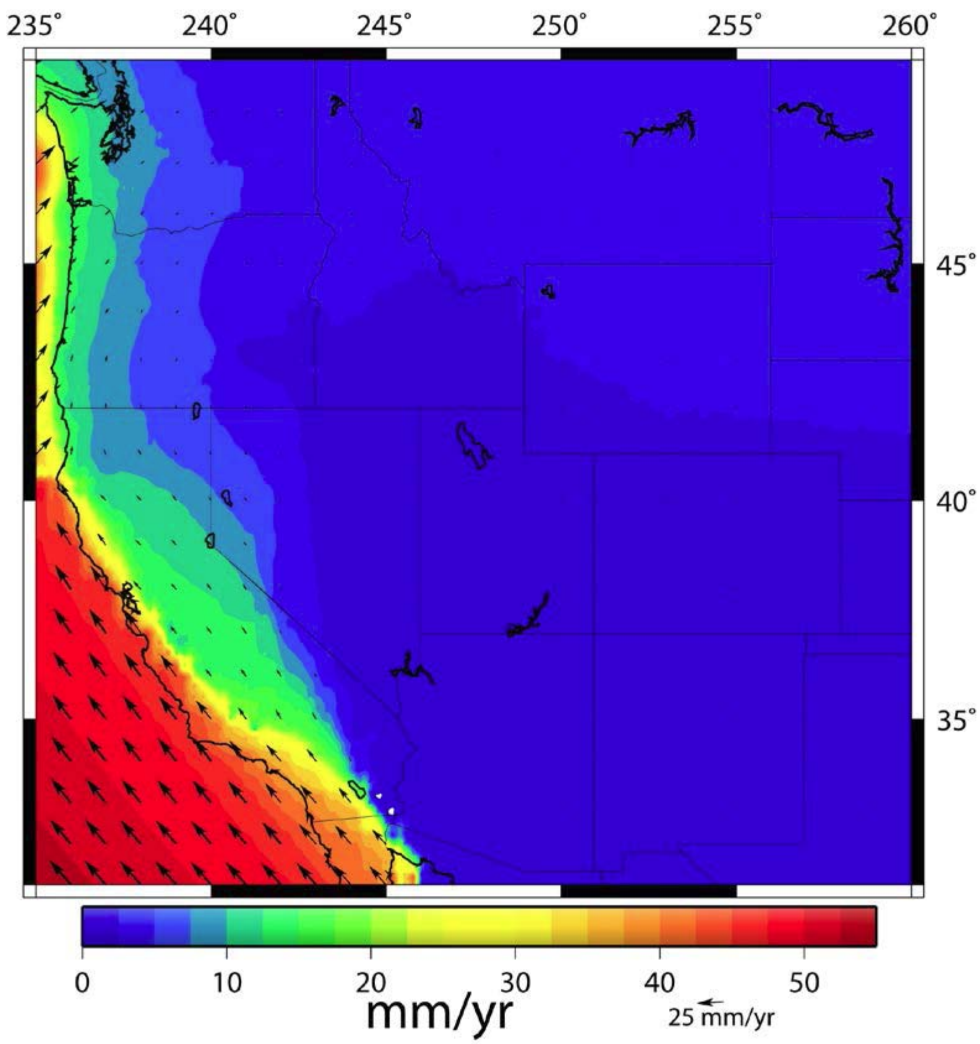

Figure 13 (9): Horizontal velocities along the California coast, where the North American and Pacific plates slide past each other in a transform fault. Graphic from the User's Guide to the HTDP software, Snay and Pearson, 2011.

A horizontal velocity of 45 mm/year, which seems to be a close estimate to the area around Santa Barbara, California, would equal 2.25 meters after 50 years. The 63 points along the California coast from the area around Santa Barbara to north of San Francisco have a mean of

2.257 meters, and the maximum value is 2.337 meters. For the state as a whole, the mean estimated displacement is 1.14 meters.

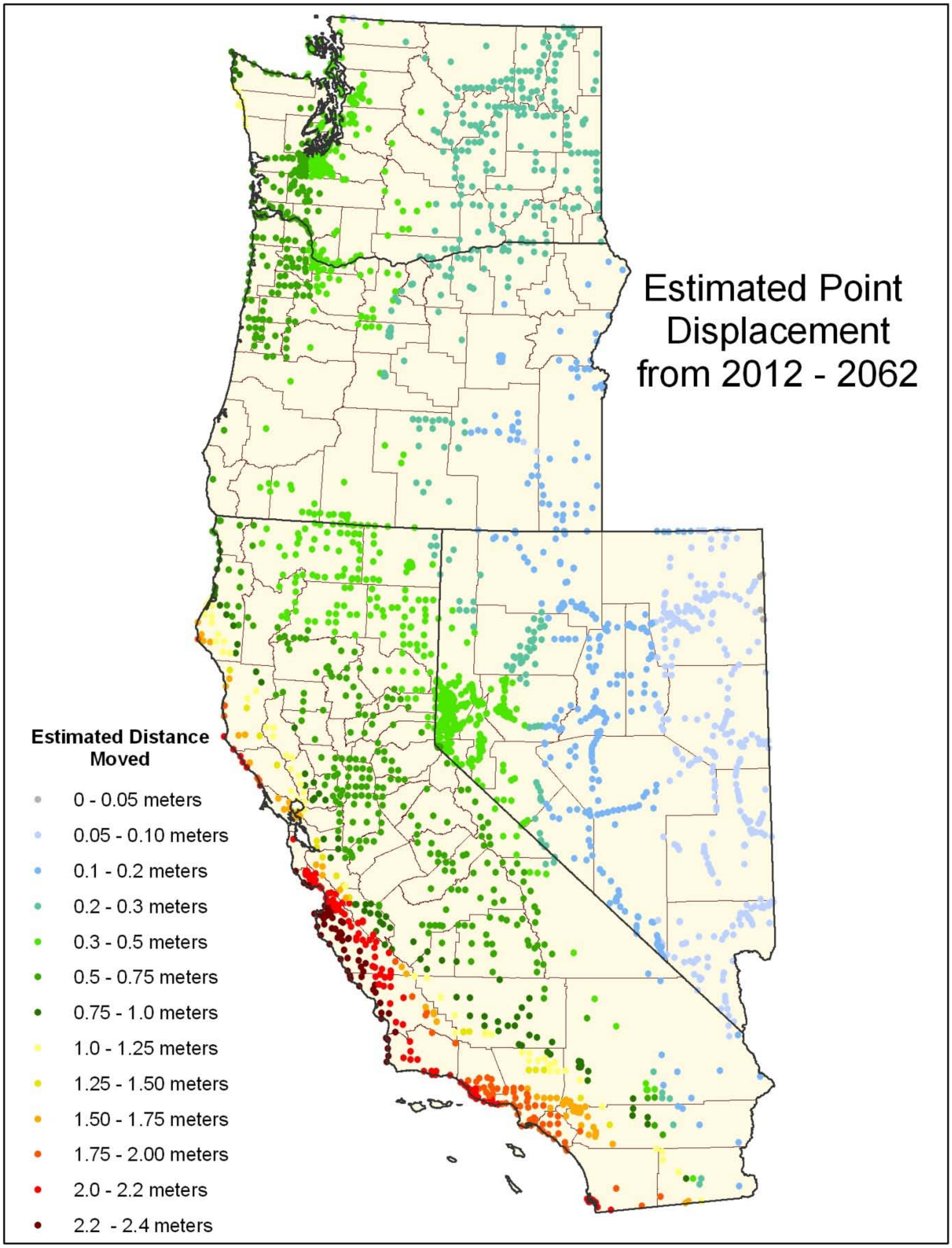

Figure 14: Horizontal velocities in the four western states, as calculated by the HTDP software.

Most of the continental United States would potentially see displacements of 0.2 meters or less after 50 years. Surprisingly, the area with the lowest estimated displacement – less than 0.05 meters - is the desert area west of Salt Lake City and extending into Idaho. This is the area of the ancient Lake Bonneville, and possibly the liquefaction potential in this area would prevent much horizontal movement. The lowest displacement calculated was in Idaho, at 0.0351 meters

Figure 15: The gray points near the Nevada-Utah-Idaho border represent the smallest estimated movement in the CONUS, of less than 0.05 meters.

Figure 16: The colors selected for the symbology have anything less than 1.0 meters as green and anything less than 0.3 meters is blue.

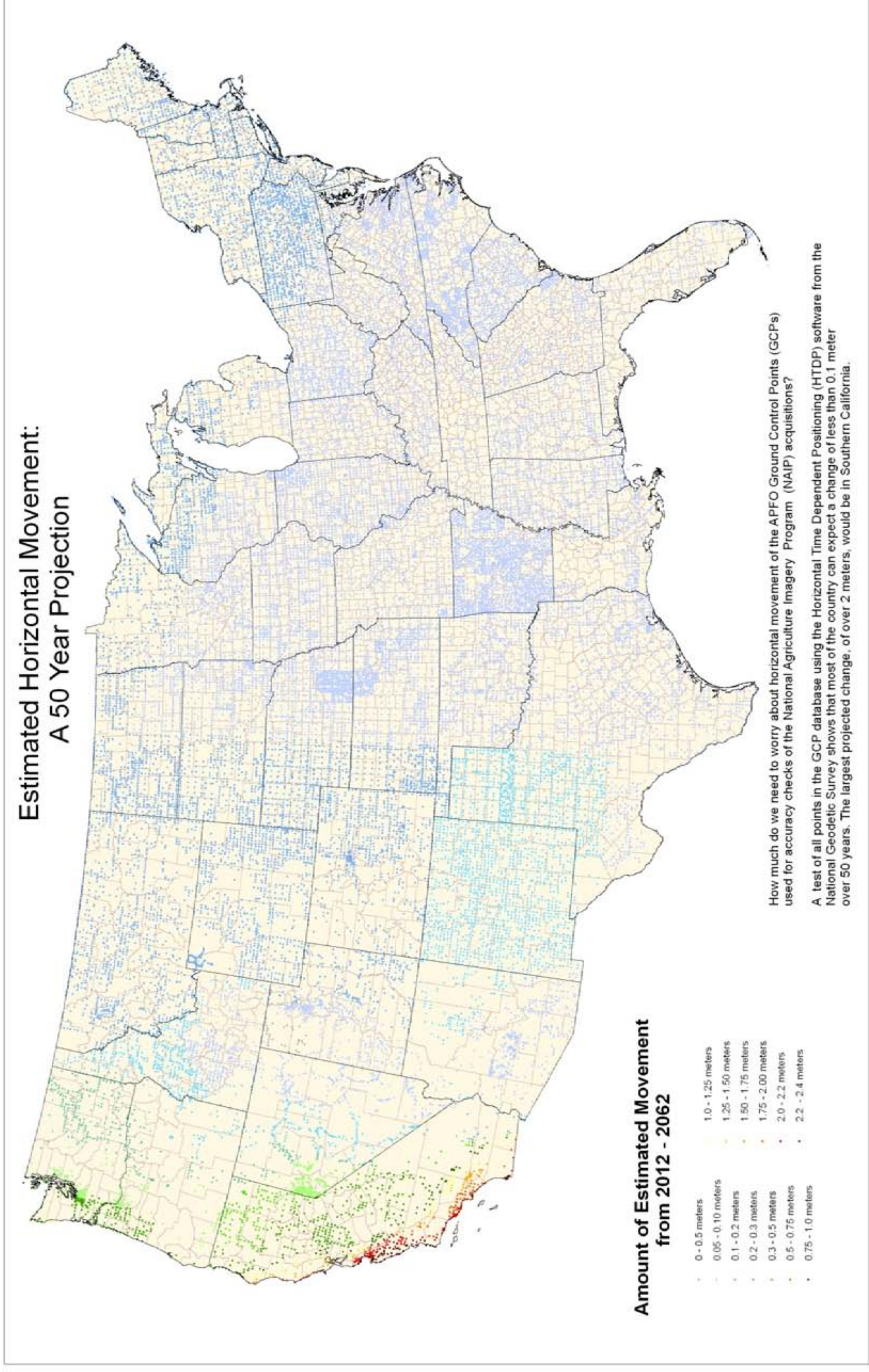

Figure 17: Most of the points in the APFO database have a predicted displacement of less than 0.1 meter.

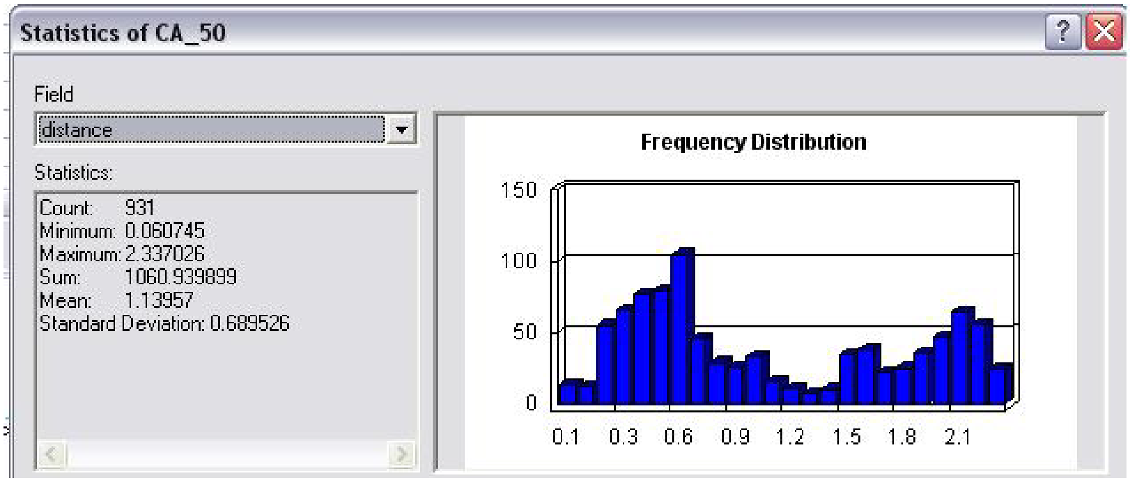

Figure 18: As expected, the range of values in California is the largest of all the CONUS states, at 2.277 meters, and the maximum predicted displacement is the largest, at 2.337 meters.

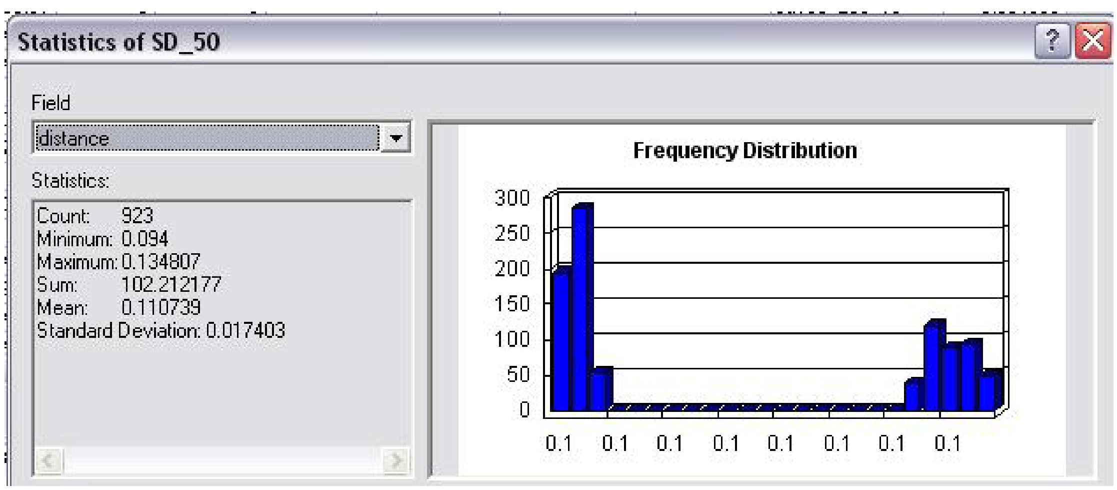

Figure 19: Some of the Midwestern states displayed two clusters of offset values, which resulted in a pattern of change down the middle of the map. This reflects a small change in the model, but since both clusters average 0.1 meter, it is of little consequence.

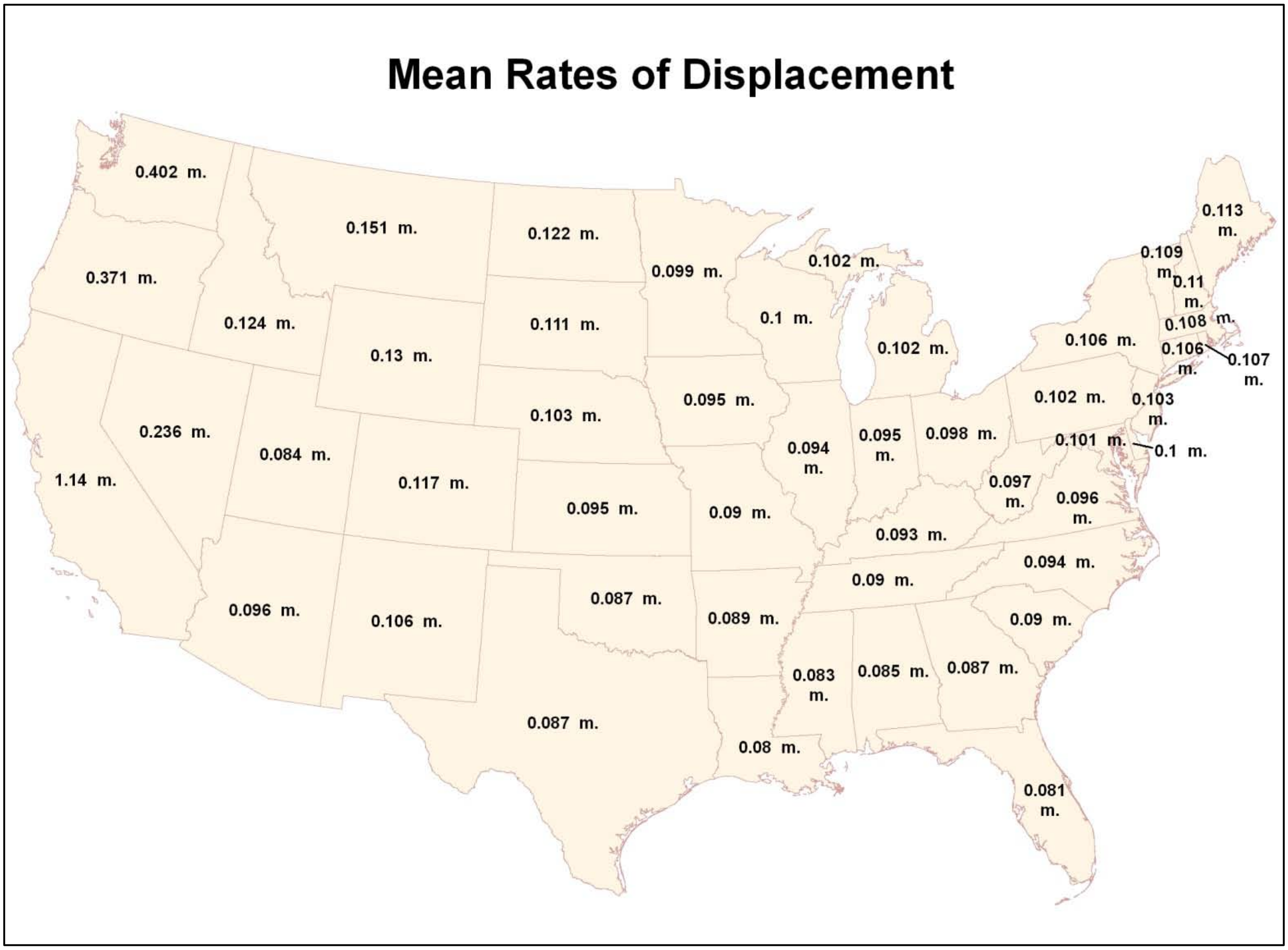

Figure 20: For all but four of the CONUS states, the mean estimated displacement rounds to 0.1 meter after 50 years. At present, this is a much smaller distance than the Ground Sample Distances of APFO imagery.

The APFO Ground Control database does not include many points for Alaska, since it is not a part of the NAIP program at present. Some points have been collected for use with Resource photography, and need to be considered, since this is also an area of seismic activity.

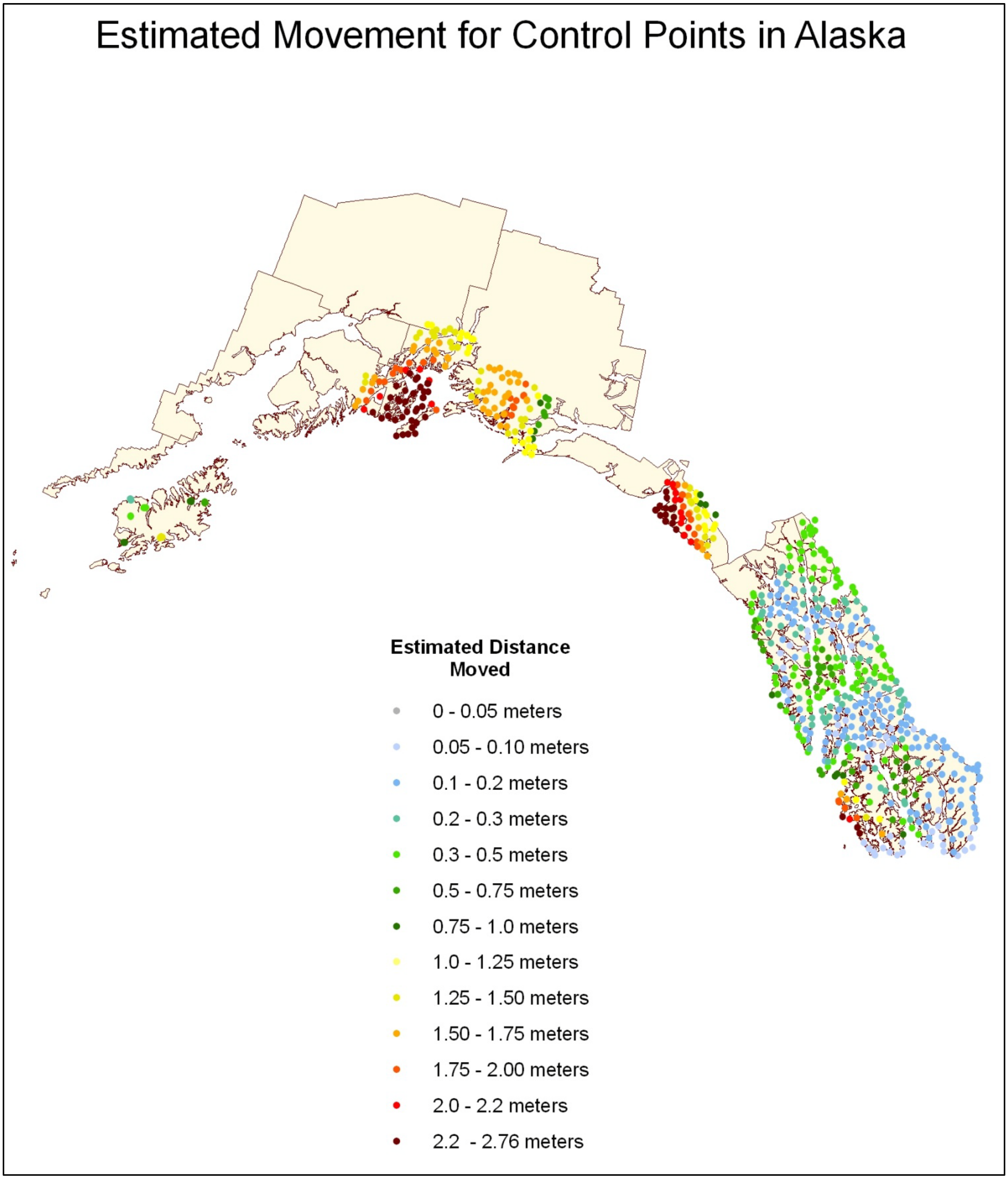

Figure 21: The potential for movement in some parts of Alaska is slightly higher than it is in California

Additional Considerations

Some other factors need to be considered before drawing conclusions about horizontal velocity and its potential effect on APFO ground control points. The first is the fact that this model deals only with the horizontal movement caused by seismic activity. There are other phenomena, such as landslides, ground subsidence, or sea level rise, which could lead to a change in the accuracy of ground control points. Snay and Pearson (2010) wrote that "significant crustal motion also occurs as a result of volcanic/magmatic activity, glacial isostatic adjustment (also called postglacial rebound), withdrawal of subsurface fluids (water and petroleum), sediment compaction, and various types of crustal loading (tidal, atmospheric, hydrologic)." These are phenomena which might merit attention at some point, by NGS and by APFO.

Another big consideration is the fact that this model deals only with horizontal motion, with no calculations for vertical changes. In areas of subduction, that is something which should probably be considered. In fact, that may soon change, since the designers of the software are working in that direction. Snay and Pearson (2010) write:

> NGS is planning to create a three-dimensional version of HTDP which may simply be called TDP for time-dependent positioning. The availability of a tool for estimating vertical crustal motion is especially important for maintaining accurate vertical coordinates on passive reference stations, because observations to measure such coordinates are performed so infrequently. To some unknown degree, the lack of such a tool compromised the accuracy of the NAD 83 (NSRS2007) ellipsoid heights that were calculated in 2007 for ≈70,000 passive reference stations distributed across the nation using GPS observations spanning approximately two decades.
>
> At this time, a current NGS project is underway to estimate three-dimensional velocities for all stations in the United States CORS network that have been operational for at least three years. NGS expects the computations of these CORS velocities to be completed by the fall of 2010. NGS will then embark on developing a model to estimate the three-dimensional velocity at any location in CONUS. A TDP release date occurring during the 2011-2012 winter is anticipated.

The article segues into the discussion of a three-dimensional model within the paragraph discussing other reasons for movement. The paragraphs quoted above do not mention these other phenomena, but they hopefully have the attention of NGS.

Another consideration is the continual upgrading of the reference frames. While alluding to the fact that NAD 83 (CORS) is probably the most commonly used reference frame at present, the software allows users to transform positions to "other popular terrestrial reference frames, including all realizations of the International Terrestrial Reference System (ITRS) and all realizations of the World Geodetic System of 1984 (WGS84). " [HTDP treats NAD 83 (CORS) and WGS84 as equivalent.]

Because NGS has been continually re-adjusting and changing the reference frames, mixing coordinates from different versions of NAD 83 might give the appearance of a shift, as illustrated in Figure 22. On a statewide scale, this shows the differences between NAD 83/2001 and NAD 83(NSRS2007).

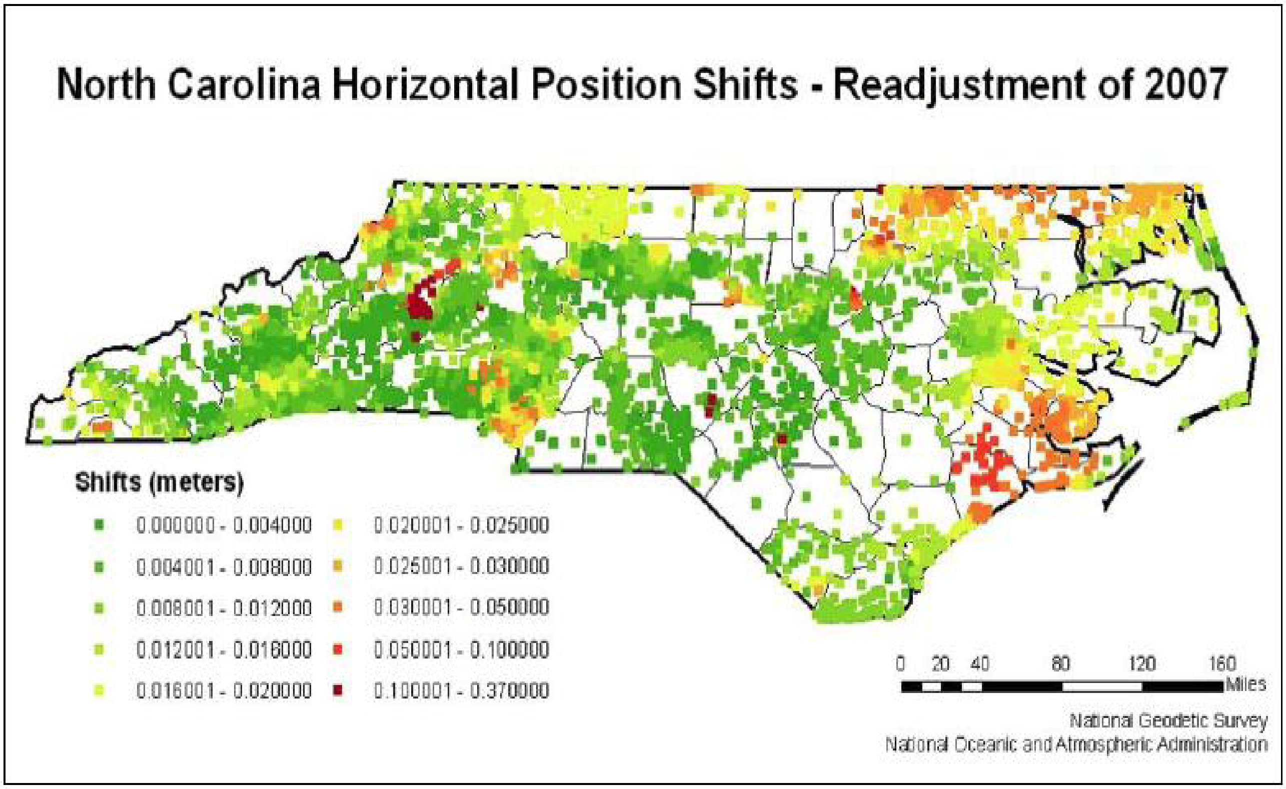

Figure 22: The positional shifts in North Carolina due to a reference frame re-adjustment.

The Chief Geodesist of NGS, Dru Smith, states that the HTDP velocities do not align with CORS. As more knowledge is gained, and newer methods developed, the process of definitively determining positions on the earth remains elusive.

Within NGS' Online Positioning User Service (OPUS) all coordinates are referred to the International Terrestrial Reference Frame of 2000 (ITRF2000). HTDP is used to convert these points into NAD 83. Snay and Pearson (2010) state that "NGS plans to update OPUS in the near future to process all GPS data so that the computed coordinates are referred to the newly derived terrestrial reference frame known as ITRF2008. The updated OPUS utility will then apply HTDP to convert these ITRF2008 coordinates, referred to the midpoint of the GPS observing session, to corresponding NAD 83 coordinates, probably referred to 2010.00 (January

1, 2010.)" They advise caution when comparing coordinates which may have different epoch dates, or have been processed with different reference frames.

A simple test with a few points in Delaware predicted "movement "of over two meters when mixing different input and output reference frames (NAD 83 and ITRF). As the years go by, it will be important to keep abreast of changes in the currently used reference frames, and, if necessary, convert the control point database to whichever is in common use. ITRF is being promoted as the next great development, but that will remain to be seen. It will be necessary for APFO to ensure that the most current and common reference frame is being used for imagery specifications, Digital Elevation Models (DEMs), production GCPs, and other elements used in imagery acquisition and distribution.

A 2002 paper from the California Spatial Reference Center (University of California at San Diego) stated that the NGS had decreased its commitment to geodetic control projects in the preceding 10 – 15 years, primarily because of budget constraints. As a result, CSRC was advocating for the development of a statewide control network as a part of a "complete" spatial reference system. In the 10 years since this was written NGS has updated the HTDP software, and has plans for future development. However, it would be wise to conduct further research into the activities of the CSRC, and other groups, as well as the activities of the NGS.

Conclusion

After running the HTDP program on all APFO ground control points in CONUS, and seeing that a minimal amount of movement from seismic activity is predicted for most of the country within 50 years time, it would be easy to dismiss horizontal velocity as something which will not be an issue for most of the points in our database. In the short term, this is probably correct. Most of the predicted displacements are less than half the size of the 1 meter pixels in current NAIP imagery, and they are much smaller than the ability of an inspector to distinguish in repeated measurements. Even the displacement after 10 years in a seismically active area might be difficult to perceive on a succession of images.

In addition, it is very difficult to predict what the future will hold in this field. It is highly unlikely that APFO would be using the same inspection process 50 years from now; it is also very possible that the imagery product itself will be very different. We don't know what sort of governmental programs will be in place, or if aerial imagery will still be needed. It might be a good guess that imagery resolution would be much finer, and that it would be displayed in three dimensions. The time between updates might be much shorter, and satellites might be playing a larger role in imagery acquisition. There will probably be much more interaction between a governmental all-inclusive imagery program and the large scale imaging used by farm machinery at a field level (precision agriculture). It is also impossible to predict the changes which may occur in agriculture and the way in which crops are cultivated.

But no matter what happens, the laws of mathematics will not change, and the principle of triangulation will not be updated. In some manner, geodetic control will be necessary, in order to continually model the earth for the myriad mapping applications which exist and will be created. It is wise to be fore-sighted, and to prepare for any eventualities we might be able to conceive of. As a result, APFO should:

1. Record an epoch date (collection date) for all points in the database. This may require a close examination of the supplemental data, since this date is often included on survey sheets. In cases where there is more than one observation date, NGS recommends using the midpoint of the observation period. Snay (1999) writes " …it is inappropriate to specify positional coordinates for these locations without also specifying the date for which these coordinates correspond. …For instance, NAD 83 positional coordinates for Continuously Operating Reference Stations (CORS) are currently specified for an epoch date of January 1, 2002 (except in Alaska where an epoch date of January 3, 2003 is used because of a major earthquake.)"

2. Emphasize the importance of including the collection (epoch) date in the main file for control points whenever these are obtained from outside sources. Be certain that these dates are included in the database.
3. Include an ellipsoid height with all new acquisitions, and make this a requirement for any new acquisitions. This will be included in the HTDP software in the near future, and may be a part of the imagery itself at some point.
4. As points are acquired for Alaska, Hawaii, and the PAC Basin, be sure that they include an epoch date and ellipsoid height and are held to the same standards as existing ground control points.
5. If high quality GPS resources are ever available for Farm Service Agency offices, re-survey some of the existing points, and apply a collection date to the new observation. In areas of seismic activity, aggressively seek a way to re-survey points, or to acquire new ones.
6. Re-examine the USGS points. There are a great many USGS points in the database with no epoch date. It might be a good idea to research the origin of these points and decide on a possible default epoch date. Snay (1999) stated that the current [1999] default epoch date is May 7, 1991; this "approximates the midpoint of the time interval during which federal, state and local institutions jointly conducted a high accuracy GPS survey involving ~ 250 sites distributed throughout California." USGS has confirmed that many of the points are old, and that dates would not be easy to find. Many of the USGS points are not very clear – even if they are clearly visible (such as the middle of an intersection) they are difficult to measure precisely. As the years go by, and more precise points are collected (with epoch dates), these could be gradually "retired."
7. Consider the possibility of using control derived from higher resolution imagery or LiDAR in areas where a significant change in position is possible.
8. Dr. Brian Luzum, head of the Earth Orientation Department of the U.S. Naval Observatory, recommends that points within 100 km of an earthquake not be used until they can be re-surveyed. It might be wise to research the locations of recent earthquakes and control points, and see if they could be re-surveyed, or if newer, better points could be acquired.
9. Consider creating coordinate fields with "homogenized" epoch dates – standardize all of the positions with the same hypothetical date. For most of the country, this would be a very minimal change, and possibly not worth the effort. Perhaps this could be automated in some way as part of the control point loading procedure. This would be primarily for APFO reference purposes.
10. Maintain a connection with the work of the NGS, as they continually update reference frames and the HTDP software. Download new versions of the software and rerun it,

especially on points in seismically active areas. Do more research on the ITRS for general understanding as it may relate to imagery programs.

11. Use the software to update positions after seismic events; or arrange to have points resurveyed. Periodically “check in” with NGS as the years pass to see what events have produced changes in the model.
12. When NGS completes its 3-D TDP software, re-run the software in areas where activities such as volcanic activity, ground subsidence or isostatic rebound may be occurring. If there is sufficient movement, consider re-surveying or acquiring new points, as we might do in California or Alaska.
13. Monitor locations such as the New Madrid Fault or Charleston, SC which have been the site of historical seismic events. At present many have very low projected movement, but there might be a chance of future activity in the area.
14. Check to see if NGS has expanded the model to include other natural (or unnatural) disturbances, and decide if this warrants an update of points in the area. See if any other organization has modeled crustal changes due to forces besides earthquakes.
15. Coordinate with states which might have their own programs for monitoring seismic activities and creating a ground control network.
16. As the years pass quickly by, maintain the flame of interest in geodetic control and movement of points, horizontally and vertically. Thorough preparation now may save time, effort, and money in future years.

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